

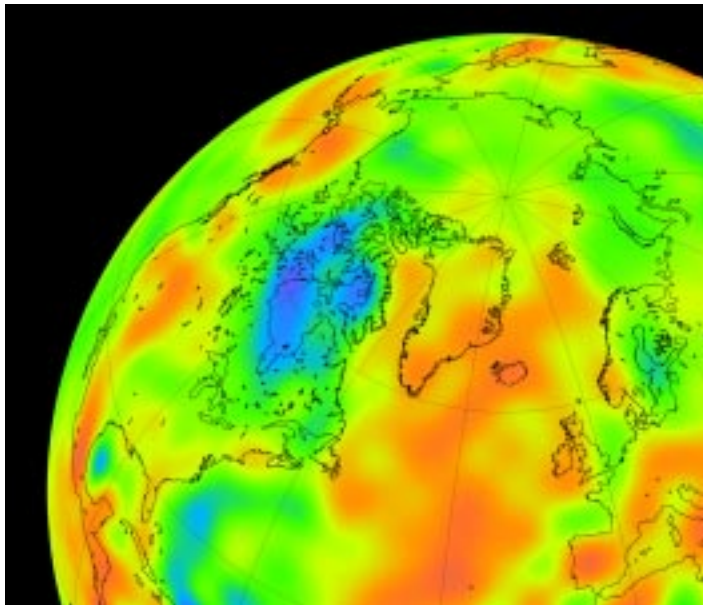
What Are the Dynamics of the Mantle and Crust, and How Does the Earth's Surface Respond?

Expected Accomplishments

- Global measurement of vertical intraplate deformation at mm/yr accuracy
- Measurement of global seafloor topography at 50-m vertical accuracy and 5-km horizontal resolution
- Improved measurements of the Earth's rotation and length of day (LOD)
- Integration of space-based geodetic observations with complementary seismic imaging studies

Benefits for the Nation

- Understanding the nature of mantle and crustal dynamics that give rise to earthquakes and volcanoes
- Better prediction of sea-level change from post-glacial rebound

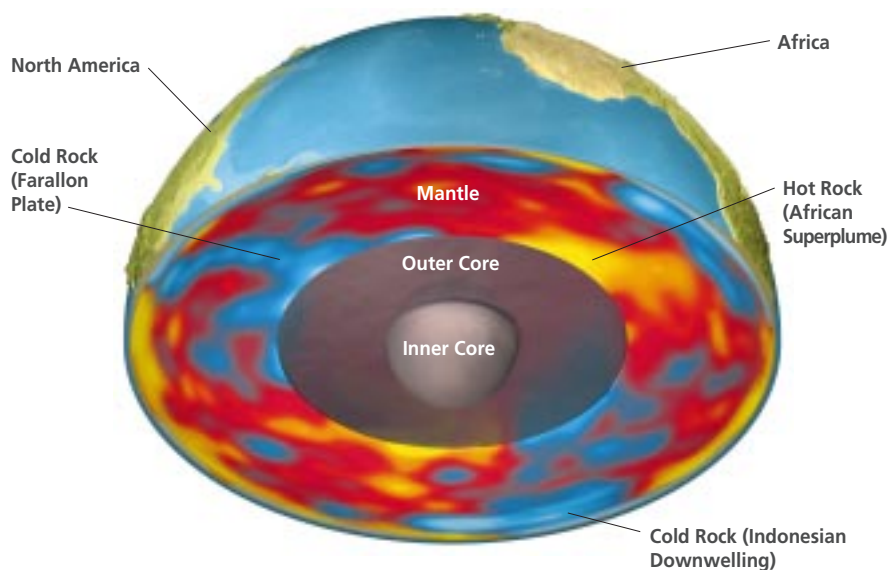


The free air gravity field of North America and the North Atlantic. Negative anomalies are indicated by cool colors and are associated with incomplete glacial rebound; positive anomalies are indicated by warm colors and are primarily associated with ocean ridge structure and western North America.

The Challenge

Tectonic processes in the mantle and crust are the engine responsible for seismicity, volcanism, and mountain building. Mantle convection converts thermal energy from radioactive decay and the cooling of the Earth into the continuous displacements responsible for plate tectonics. The deformation of the Earth's surface required to accommodate plate tectonics occurs primarily on plate boundary faults and relatively broad zones of deformation adjacent to the plate boundaries in the continents. The forces that drive the motions of the plates, however, are not well quantified. What are the relative roles of slab "pull," ridge "push," and basal tractions?

Mantle convection has been studied through computer simulations and laboratory analogue experiments, but models to date are limited in their ability to approximate Earth conditions at high resolution. Mantle seismic tomography is producing three-dimensional images of seismic velocity anomalies of increasingly sharper resolution, and studies of seismic wave anisotropy offer the promise of constraining the signature of alignment of mantle mineral grains by convective flow. The extent to which the seismic velocity anomalies seen in tomographic images are correlatable to the density anomalies that drive convective motions, however, is far from clear. The global gravity field and long-wavelength topography provide key integrative measures of these mantle density anomalies, although their interpretation requires information on the structure of the tectonic plates and the variation of viscosity within the mantle. Improved information on plate characteristics and mantle viscosity can come, in turn, from measurements of the time-dependent response of global gravity, topography, and Earth rotation to loading and unloading by glaciers, oceans, and other forcings.



Mantle cross section integrates measurements of seismic waves that have traveled through the planet. Regions where wave velocity is anomalously high (blue) are thought to denote cold, dense rock. Regions where wave velocity is anomalously low (yellow) are thought to correspond to hot, less-dense rock.

"Set the foot down with distrust on the crust of the world — it is thin."

*Edna St. Vincent Millay, from her poem, Huntsman,
What Quarry?*

Understanding mantle convection, and its coupling to the motions of the crust and lithosphere, will require a combination of approaches. Improved definition of the time-dependent gravity field and long-wavelength shape of the Earth must be combined with sharpened images of seismic wave speeds and their direction dependence as well as continued measurement of variations in Earth rotation parameters. Sophisticated models of three-dimensional, time-dependent mantle flow must ultimately be capable of predicting the full suite of observable quantities.

What We Know and Need to Learn about the Mantle and Crust

Plate tectonics is a consequence of mantle convection. Mantle processes also influence surface deformation, internal mass redistribu-

tion, and changes in Earth's length of day (LOD).

While we have determined the relative velocities among plates from surface geodetic observations, we do not know how mantle flow is coupled to the motions of the tectonic plates. There are major uncertainties concerning the geometry of mantle flow at depth. We do not know, for instance, whether the pattern of mantle convection is simple or complex. We have a relatively poor understanding of the dynamics of subduction at ocean trenches, or the mechanism for initiation of new subduction zones. While we generally understand the large-scale thermal structure of mid-ocean ridges and oceanic plates with ages less than about 50 million years, there are still questions about structure at small spatial scales as well as for older oceanic plates and continental plates. We lack information

on the deep structure and distribution of mantle plumes. We do not understand in detail the mechanisms that lead to island volcanism adjacent to ocean trenches. While oceanic crust is thought to be formed by partial melting of mantle rock at depth beneath an ocean ridge, we don't understand how continental crust is formed or whether recycling of the lower continental crust into the mantle is an important process.

Next Steps

The observational approaches over the next 25 years must cover a broad range to answer these questions. Global gravity measurements will illuminate the time-varying gravity signal, which holds keys to understanding post-glacial unloading and ocean loading, and the mechanics of subduction. InSAR and GPS measurements of vertical deformation at millimeter/year accuracy and tens of kilometers resolution are needed both in the near term and over longer time scales to complement time-dependent gravity measurements. High-resolution radar altimeters will reveal the small-scale gravity signals of plate boundary and volcanic processes beneath the oceans. Terrestrial reference frame measurements using GPS, SLR, and VLBI will further enhance an understanding of the mechanisms of core-mantle and mantle-crust coupling. Changes in the Earth's length of day and long-wavelength gravity field provide important information about mass movements throughout the Earth's mantle. Through diverse observational opportunities and high-performance computer modeling, the critical connections of the mantle and crust to other components of the Earth system can be characterized and better understood.